The success of critical velocity protocol on predicting 10000 meters running performance

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Authors’ Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim

The study aims to evaluate which of the critical velocity (CV) estimates of the three widely used models and the best-fit model successfully predict the running performance of 10000 meters.

Material and Methods

The group of participants in this study consisted of 11 British endurance athletes. The CV estimations were obtained from the models with the athletes’ running velocity and exhaustion times of 1500, 3000, and 5000 meters (m). The information was taken from a website where the results of the British athletes are recorded. In terms of selecting endurance athletes, the data of the athletes who ran 1500 m, 3000 m, 5000 m, and 10000 m in the same two years were included in this study. By fitting the data into mathematical models, the CV estimates of the three mathematical models and the individual best-fit model were compared with the 10000 m running velocity. The CV estimates were obtained by fitting the relevant data on the running velocity, exhaustion time, and running distance of the three running distances of athletes to each of the three mathematical models.

Results

10000 m running velocity and times of the athletes corresponded to 19.65 ± 1.26 km/h and 30.4 ± 1.94 minutes, respectively. The CV values obtained from the three mathematical models and 10000 m running velocity were similar (p > 0.05). Although the lowest total standard error levels were obtained with the best individual fit method, the 10000 m running velocity was overestimated (p < 0.05).

Conclusions

Three mathematical models predicted 10000 meters of race velocity when an exhaustion interval between 2-15 minutes was used. Even though the mathematically most valid CV value was obtained with the best individual fit method, it overestimated the 10000 m running velocity. When comparing the values of CV and the velocity of running 10,000 meters, our study suggests using the model. This is because the model has the smallest effect size, and there is no statistically significant difference in the total standard error level between the model and the best-fit model.

Keywords: aerobic capacity, critical velocity, endurance athletes, track and field

Introduction

While the duration asymptotic of hyperbolic relation between running velocity and duration is defined as critical velocity (CV), the curvature constant represents the total work that can be done with our anaerobic storages by meter grade. Since CV theoretically represents the highest running velocity which can be sustained by aerobic energy system without fatigue [1], CV is utilized as a decent performance capacity index among endurance sports [2, 3, 4]. On the other hand, in an exercise that is being sustained above CV rates, exercise can’t be sustained for very long times due to limited anaerobic distance capacity (ADC) usage, and the athlete runs short soon exhausted. Today, CV is defined as separating the heavy exercise domain from the severe exercise domain and representing the highest exercise intensity that can be sustained without a gradual increase in anaerobic contribution. The literature has shown that at exercise intensities corresponding to the severe exercise domain, a physiological steady state cannot be maintained since blood [lactate], and VO2 progressively reach their maximal levels at fatigue [5, 6, 7]. It is particularly important to understand how different exercise-intensity domains and their corresponding VO2 profiles and metabolic responses are linked to fatigue mechanisms and manipulate exercise tolerance, and therefore a measurement of the boundary between each exercise-intensity domain is essential for optimizing training programs. CV, a threshold intensity that separates the domain of heavy and severe exercise, is traditionally and commonly estimated using one of three mathematical models. These are: total linear distance [8], linear velocity, and non-linear two-parameters model [9]. These models, along with CV, can also make anaerobic distance capacity (ADC) estimation. ADC states the work we can do with our anaerobic storage by sort of meter. Both parameters

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obtained from these models are included in our training programs as important exercise stimuli for the development of aerobic and anaerobic capacity [10]. Fitting the distance, running time or running velocity parameters using any of the models allows us to individually estimate the CV that can be sustained over a certain period of time [11]. Such data are of great importance for trainers in predicting performance or determining training intensities, especially for middle and long-distance runners. The main reason for this importance is to train at the race intensity or velocity as a method of increasing long-term performance [12]. The CV, which represents the highest exercise intensity at which a physiological steady-state can be maintained, can be estimated using running distances due to its mathematical relationship. For CV and ADC estimations, two data related to exhaustion time, running velocity, and distance travelled of three or four running tests that ended in exhaustion between 2 and 15 minutes are fitted to one of the mathematical models [13]. Vanhatalo et al. have shown the estimation of 5000 meters (m) running performance using running distances ranging from 600 m to 2000 m in their study [14]. After the distance completed is plotted against time to be able to estimate that distance, linear regression analysis allows the calculation of the slope (CV) and the asymptote, thus allowing performance estimates of a race distance [14]. Hughson et al. showed that the CV estimated from the hyperbolic model overestimates the actual performance of 10 km [11]. Many research groups have compared CV with actual running performance velocity [15, 16, 17, 18]. However, CV and ADC estimations may differ between 5-20% depending on the preferred mathematical model [19, 20, 21]. Since the estimated parameters in the CV concept and the standard error percentages of the parameters differ according to the models, the model that gives the lowest standard error percentage of the parameters is generally recommended as the reason for preference. Based on this, the best individual fit model method was developed [21, 22, 23]. According to this method, the model with the lowest percentage sum of the standard error of CV and ADC is accepted as the most valid method mathematically. A limited number of studies have examined the best individual fit method [24, 25, 26, 27]. However, most of these studies are on CV, the cycling form of critical power (CP). The CV concept, and its success in estimating running velocity such as 5000 m, 10000 m, half marathon, and marathon has been studied before [28, 29, 30, 31]. These studies generally sought to estimate endurance distances by choosing one of the three commonly used models. Although mathematical model selection is an important variable affecting CV estimation, there are not enough studies on determining the model that provides CV estimation, which is most closely related to performance ability in long-distance branches. Therefore, this study aims to evaluate the success of the CV estimates of the three traditional mathematical models and the best fit model used as a field-based approach in estimating the actual running velocity of 10000 m.

**Materials and Methods**

**Participants**

The research group in this study consists of 11 endurance athletes. The descriptive data of the participants are shown in Table 1. While selecting the endurance athletes, the data of the athletes who ran 1500 m, 3000 m, 5000 m, and 10000 m in within two years were included in this study. The data of the participants for 1500 m, 3000 m, 5000 m, and 10000 m were obtained from the open access website [32]. Since the data were publicly published, no relevant permission was obtained.

**Table 1. Running velocity and exhaustion times of 1500, 3000, 5000 and 10000 meters**

<table>
<thead>
<tr>
<th>Participants</th>
<th>1500 meters</th>
<th>3000 meters</th>
<th>5000 meters</th>
<th>10000 meters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (minute)</td>
<td>Velocity (km·h⁻¹)</td>
<td>Time (minute)</td>
<td>Velocity (km·h⁻¹)</td>
</tr>
<tr>
<td>M. F.</td>
<td>3.57</td>
<td>25.2</td>
<td>7.58</td>
<td>23.7</td>
</tr>
<tr>
<td>C. H.</td>
<td>3.93</td>
<td>22.9</td>
<td>8.42</td>
<td>21.4</td>
</tr>
<tr>
<td>N. E.</td>
<td>3.92</td>
<td>23.0</td>
<td>8.50</td>
<td>21.2</td>
</tr>
<tr>
<td>D. N.</td>
<td>4.02</td>
<td>22.4</td>
<td>8.45</td>
<td>21.3</td>
</tr>
<tr>
<td>M. C.</td>
<td>4.35</td>
<td>20.7</td>
<td>9.25</td>
<td>19.5</td>
</tr>
<tr>
<td>J. M.</td>
<td>3.72</td>
<td>24.2</td>
<td>8.18</td>
<td>22.0</td>
</tr>
<tr>
<td>P. M.</td>
<td>4.02</td>
<td>22.4</td>
<td>8.43</td>
<td>21.5</td>
</tr>
<tr>
<td>J. R.</td>
<td>4.02</td>
<td>22.4</td>
<td>8.90</td>
<td>20.2</td>
</tr>
<tr>
<td>A. M.</td>
<td>3.98</td>
<td>22.6</td>
<td>8.38</td>
<td>21.5</td>
</tr>
<tr>
<td>D. M.</td>
<td>4.20</td>
<td>21.4</td>
<td>8.95</td>
<td>20.1</td>
</tr>
<tr>
<td>B. J.</td>
<td>4.07</td>
<td>22.1</td>
<td>8.93</td>
<td>20.1</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>3.98±0.21</td>
<td>22.67±1.23</td>
<td>8.54±0.45</td>
<td>21.12±1.16</td>
</tr>
</tbody>
</table>
**Research Design**

In this study, a descriptive research type was used in which the data obtained from the open access site where the competition results of the endurance athletics athletes were analyzed. By fitting the data to the mathematical models, the CV estimates from the three mathematical models and the individual best-fit model were compared with the 10000 m running velocity.

**Obtaining Critical Velocity from Mathematical Models**

For the CV concept, running distances of 1500 m, 3000 m, and 5000 m were preferred, as it was recommended to fit the data that ended in exhaustion between 2-15 minutes to the models. CV estimates were obtained by fitting each of the three mathematical models from the data of the athletes’ three running distances, running velocity, exhaustion time, and running distance. The mathematical models in which the data are fitted and the equations of the models are, respectively.

**Equation 1; Linear total distance model**

The linear total distance model described as [33]:

\[ \text{Total Distance} = \text{ADC} + (\text{CV} \times t), \]

where ADC represents "anaerobic distance capacity" calculated by \( V \times t \); ADC is the intercept; CV is slope of the line; and \( t \) is finishing time.

**Equation 2; Linear velocity model**

If the running velocity is plotted against 1/time, "Linear velocity model" can be described as [11]:

\[ V = \text{ADC} \times (1/t) + \text{CV}, \]

where \( V \) represents running velocity; CV is intercept; ADC is the slope of the linear relationship; and \( 1/t \) is the slope of the linear relationship.

**Equation 3; Non-linear 2 parameters model**

When the \( t \) is plotted against particular running velocity, the mathematical relationship is shown as a hyperbolic function. The non-linear equation of the inverse relationship between running velocity (\( V \)) and time is described as [34]:

\[ t = \frac{\text{ADC}}{(V - \text{CV})}, \]

where \( t \) is finishing time; \( V \) is running velocity; CV is the asymptote for velocity data; and ADC is a finite amount of work as a curvature constant

**The Best individual fit model**

The model with the lowest sum of the standard errors of CV and ADC estimated from linear total distance, linear velocity, and non-linear 2-parameter models was accepted as the individual best-fit model. CV and ADC from the best-fit model were expressed as \( CV_{\text{best}}, \) and \( ADC_{\text{bestfit}}, \) respectively.

**Statistical Analysis**

The results were evaluated by using SPSS 21.0 (SPSS Inc., Chicago, USA). All data were stated as average ± standard deviation. The normality of data was tested by the Shapiowilk normality test. The difference between measurements was analyzed with paired sample test. Statistical meaning criteria were accepted as \( p<0.05. \) The effect size was analyzed based on Cohen’s. The effect size of the differences was categorized as trivial (< 0.2), small effect (0.2–0.5), medium effect (0.5–0.8), and large effect (> 0.8). A 95% confidence interval (95% CI) was applied for the difference between means.

**Results**

The 10000 m running velocity and times of the athletes corresponded to 19.65±1.26 km·h\(^{-1}\) (Table 2) and 30.4±1.94 minutes. The 10000 m running velocity and CV obtained from the mathematical models and the best fit method are shown in Table 2.

The CV obtained from the three mathematical models was similar to the running velocity of 10000

**Table 2.** The running velocity for the 10000 meters, critical velocity estimations obtained from the mathematical model and the best individual fit method

<table>
<thead>
<tr>
<th>Participants</th>
<th>10000 m running velocity (km·h(^{-1}))</th>
<th>Linear total distance (km·h(^{-1}))</th>
<th>Linear velocity (km·h(^{-1}))</th>
<th>Nonlinear 2 parameters (km·h(^{-1}))</th>
<th>The Best Individual Fit (km·h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. F.</td>
<td>22.36</td>
<td>22.25</td>
<td>22.30</td>
<td>22.20</td>
<td>22.30</td>
</tr>
<tr>
<td>C. H.</td>
<td>20.27</td>
<td>20.66</td>
<td>20.47</td>
<td>21.01</td>
<td>20.47</td>
</tr>
<tr>
<td>N. E.</td>
<td>20.11</td>
<td>20.34</td>
<td>20.11</td>
<td>20.75</td>
<td>20.11</td>
</tr>
<tr>
<td>D. N.</td>
<td>19.64</td>
<td>20.27</td>
<td>20.29</td>
<td>20.28</td>
<td>20.29</td>
</tr>
<tr>
<td>M. C.</td>
<td>17.48</td>
<td>17.75</td>
<td>17.96</td>
<td>17.59</td>
<td>17.96</td>
</tr>
<tr>
<td>J. M.</td>
<td>20.55</td>
<td>21.24</td>
<td>20.87</td>
<td>20.69</td>
<td>20.69</td>
</tr>
<tr>
<td>J. R.</td>
<td>18.83</td>
<td>18.50</td>
<td>18.49</td>
<td>18.57</td>
<td>18.49</td>
</tr>
<tr>
<td>A. M.</td>
<td>18.90</td>
<td>19.33</td>
<td>19.71</td>
<td>19.08</td>
<td>19.71</td>
</tr>
<tr>
<td>D. M.</td>
<td>18.60</td>
<td>18.58</td>
<td>18.71</td>
<td>18.48</td>
<td>18.71</td>
</tr>
<tr>
<td>Average</td>
<td>19.65±1.26</td>
<td>19.84±1.30</td>
<td>19.83±1.22</td>
<td>19.87±1.35</td>
<td>19.92±1.20</td>
</tr>
</tbody>
</table>
Although the lowest total standard error levels were obtained with the best individual fit method (Table 4), it overestimated the 10000 m running velocity.

**Discussion**

The aim of this study was to evaluate the success of the CV estimates of the three commonly used models and the best-fit model in accurately predicting the 10000 m running performance. CV estimates can differ by 24% according to the mathematical models used [19, 20]. However, according to our findings, the CV estimates obtained from the mathematical models were quite similar to each other. This high vulnerability in CV estimations is due to the non-linear three-parameter and exponential model that predicts the lowest and highest CV rather than linear models and non-linear two-parameter models [19, 20]. Therefore, it is natural that the CV estimates obtained from the three models we used are close to each other. As expected, the best individual fit model overestimated the 10000 m running velocity, although it gave the lowest overall standard error level, giving a more mathematically valid CV estimate (CV_{bestfit}). Three commonly used mathematical models gave CV values close to 10000 m running velocity. Although the p-value between the CV values of the three models and the 10000 m running velocity is over 0.05, when the effect sizes are examined, it is interpreted that the most appropriate model is the model followed by the non-linear two-parameter and linear total distance model. Dekerle et al. emphasized that the model provides a better CV estimation compared to the other two-parameter models [35]. In the current study, besides the model estimating the 10000 m running velocity correctly, the fact that the total standard error level does not differ significantly from that of the best individual fit model makes it stand out among other models. Nimmerichter et al. found that CV estimates obtained from three mathematical models underestimated the 5000 m running velocity [31]. Kranenburg and Smith compared the CV estimates they obtained with the CV concept, both in the laboratory and on the track and field, with a running velocity of 10000 m [36]. In their studies, it has been reported that the CV on the track and field predicts 10000 running velocity correctly and has a high correlation, while the CV on the treadmill is estimated as high as 2% [36]. CV estimates may differ by 5-10% when data from different exhaustion intervals (2-10 minutes, 2-15 minutes, and 2-20 minutes) are fitted to the models [21]. Kranenburg and Smith used test data between 2 and 15 minutes in their study, in which they estimated the 10000 m running velocity [36]. Since CV estimates from models in our current study were obtained from test data between 2 and 15 minutes, other models were successful in estimating 10000 m running velocity, except for the best individual fit method. Simões et al. [18] and Kranenburg and Smith [36] have found

**Table 3.** Statistical results between 10000 m running velocity and critical velocity obtained from mathematical models

<table>
<thead>
<tr>
<th>Variables</th>
<th>10000 m – Linear total distance model</th>
<th>10000 m – Linear velocity model</th>
<th>10000 m – Nonlinear 2 parameters model</th>
<th>10000 m – The Best individual fit model</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-value</td>
<td>0.085</td>
<td>0.138</td>
<td>0.110</td>
<td>0.033*</td>
</tr>
<tr>
<td>T-value</td>
<td>1.909</td>
<td>1.611</td>
<td>1.751</td>
<td>2.476</td>
</tr>
<tr>
<td>95% CI</td>
<td>-0.41, 0.03</td>
<td>-0.44, 0.07</td>
<td>-0.50, 0.06</td>
<td>-0.52, -0.03</td>
</tr>
<tr>
<td>Effect Size</td>
<td>0.59</td>
<td>0.48</td>
<td>0.53</td>
<td>0.75</td>
</tr>
</tbody>
</table>

*Statistically significant difference

**Table 4.** Results from the mathematical model and the best individual fit method

<table>
<thead>
<tr>
<th>Models</th>
<th>(R^2)</th>
<th>(CV) (km·h(^{-1}))</th>
<th>(SE_{CV}) (km·h(^{-1}))</th>
<th>(SE_{CV%}) (%)</th>
<th>(ADC) (m)</th>
<th>(SE_{ADC}) (m)</th>
<th>(SE_{ADC%}) (%)</th>
<th>(TE%) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear total distance</td>
<td>0.99</td>
<td>19.83±1.30*</td>
<td>0.28±0.20</td>
<td>1.45±0.96</td>
<td>185±45.6</td>
<td>47.3±22.3</td>
<td>27.9±22.3</td>
<td>29.3±25.4</td>
</tr>
<tr>
<td>Linear velocity</td>
<td>0.97</td>
<td>19.83±1.21*</td>
<td>0.31±0.18</td>
<td>1.6±0.92</td>
<td>677±111</td>
<td>108±73</td>
<td>16.0±10.7</td>
<td>17.6±11.5</td>
</tr>
<tr>
<td>Nonlinear 2 parameters</td>
<td>0.93</td>
<td>19.86±1.35*</td>
<td>0.38±0.60</td>
<td>1.9±2.9</td>
<td>664±521</td>
<td>142.6±96.8</td>
<td>30.2±31.9</td>
<td>32.0±31.3</td>
</tr>
<tr>
<td>The Best Individual Fit</td>
<td>0.94</td>
<td>19.92±1.19*</td>
<td>0.43±0.59</td>
<td>2.1±2.8</td>
<td>673±133</td>
<td>117±84.7</td>
<td>10.8±9.9</td>
<td>12.9±10.0</td>
</tr>
</tbody>
</table>

CV: Critical Velocity; ADC: Anaerobic Distance Capacity; \(SE_{CV}\): Standard error of critical velocity; \(SE_{CV\%}\): Percentage of standard error of critical velocity; \(SE_{ADC}\): Standard error of anaerobic distance capacity; \(SE_{ADC\%}\): Percentage of standard error of anaerobic distance capacity; \(TE\%\): Percentage of total error

*No statistically significant difference between CV estimations
10000 meters of race velocity was similar to CV. While Simões et al. observed a difference of only 0.4 m min⁻¹ between CV and 10000 m race velocity [18], Kranenburg and Smith have observed as little as 1.5 m min⁻¹ [36]. Pettitt et al. observed a higher difference of 4.2 m min⁻¹ between CV and 5000 m race velocity [16]. Similarly, Simões et al. found that 3000 m running velocity was significantly faster than CV, also 10000 m race velocity was not [18]. Finally, Colombo et al. have found no significant difference between the estimated CV and actual running velocity at 10000 m [15]. While not statistically significant, the difference between the actual and estimated CV observed by Colombo et al. could be practically significant as a difference of 1.03 minutes was observed for 10000 m running distance [15].

Conclusions
Consequently, three mathematical models predicted 10000 meters of race velocity when an exhaustion interval between 2-15 minutes was used. Even though the mathematically most valid CV value was obtained with the best individual fit method, it overestimated the 10000 m running velocity. When the CV values and 10000 meters running velocity are compared, our study suggests the model since the smallest effect size belongs to the model, and there is no statistically significant difference in the total standard error level of the model and the best-fit model.

Acknowledgement
The data of the participants were obtained from the open-access website https://www.thepowerof10.info [32]. Since the data were publicly published, no relevant permission was obtained.

Conflict of interest
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References


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Cite this article as:

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Received: 20.06.2023

Accepted: 21.07.2023; Published: 30.08.2023